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Long-term operation test of RPCs for the OPERA experiment

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Abstract

OPERA is one of the two detectors foreseen in the CERN Neutrino to Gran Sasso project, devoted to the detection of ν_μ into ν_τ oscillations in the parameter region suggested by SuperKamiokande data on atmospheric neutrinos. Bakelite RPCs will be used to instrument the iron yoke of the muon spectrometers. We present the results of long-term (greater than 6 months) streamer operations of real size OPERA RPCs at cosmic rays fluxes. Given the very low rate observed in the underground Gran Sasso Laboratories, under 3 km w.e., even this short time period is equivalent to more than 10 OPERA years. Results of tests with different gas mixtures are reported, in view of decreasing the streamer charge of operation for the RPCs employed in the experiment.

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1. Introduction

OPERA is part of the CERN Neutrino to Gran Sasso (CNGS) project, and it is one of the two experiments dedicated to the observation of ν_μ into ν_τ oscillations through τ appearance over a 730 km baseline. A detailed description of the detector together with its physics potential can be found in Ref. [1]. The experiment is endowed with two spectrometers for muons identification and reconstruction, mainly to reject the charm background. In each spectrometer, six planes of vertical drift tubes are used for measuring the momentum of

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muons by observing their deflection through 24 vertical magnetised iron slabs 5 cm thick, 8 m high and 8.7 m wide. The 2 cm gaps between the slabs are instrumented with bakelite RPCs [2] of size $2.9 \times 1.1\,m^2$, with a grooved edge frame in order to fit the screws that hold together the magnet. RPCs are used for tracks reconstruction inside the magnet (particularly for stopping muons), for triggering the spectrometers and for giving the "T0" to the drift tubes.

OPERA RPCs will be operated in streamer mode with large and easy-to-discriminate signals. Given the low counting rate inside the Gran Sasso underground laboratory, bakelite electrodes with resistivity greater than $5 \times 10^{11}\,\Omega\,cm$ are selected. Because of the grooves in the edge frame, particular care is taken in the linseed oil coating procedure, during which the chambers are rotated in order to avoid the formation of oil lumps near the grooves. In this paper, we present the results of long-term operation tests performed on real size prototypes of RPCs produced according both to the old and to the new procedures.

Recently, the production of hydrofluoric acid (HF) has been observed in streamer mode operated RPCs [3] filled with ternary gas mixtures composed of argon, tetrafluoroethane ($C_2H_2F_4$), and isobutane (i-C_4H_{10}). To avoid ageing effects due to damaging of the electrodes surface, with the isobutane limited to few % by gas flammability requirements, we have investigated the possibility of reducing the tetrafluoroethane to concentrations as low as 20% with the addition af small quantities (below 1%) of SF_6. The charge released in the gas for each detector count is lower, even in presence of some afterpulses due to the reduced quenching power of the mixture [4]. The reduction of tetrafluoroethane quantity with fixed isobutane concentration also lowers the operating voltage. Results of the long-term operation test performed with a mixture containing SF_6 are reported in this paper.

2. Experimental set-up

The long-term operation tests have been performed at the Gran Sasso external laboratory, at cosmic rays fluxes 1 km above the sea level. Typical counting rates are around $300\,Hz/m^2$, greater by a factor of ten with respect to those measured in the underground laboratory [5]. Considering also that the neutrino beam will be provided only six months in one year, six months of test in the external laboratory are equivalent to ten OPERA years in terms of rate, given the hypothesis that RPCs will be kept working only in presence of the neutrino beam.

The set-up is composed of six RPCs under test, labelled as RPC1, RPC2, RPC3, RPC4, RPC5 and RPC6, with the operating currents monitored at $0.1\,\mu A$ precision on the power supplies. RPC1, RPC2 and RPC3 have been produced with old production techniques, while RPC4, RPC5 and RPC6 have been produced according to the final ones. All the RPCs under test have the grooved edge frame, except for RPC1 and RPC3. The first four RPCs are equipped with orthogonal read-out strips and constitute a tower triggered by the coincidence of three scintillator slabs $2.1 \times 0.3\,m^2$ wide, therefore not covering the entire RPC area.

The detectors were first operated with a gas mixture $Ar/C_2H_2F_4/i\text{-}C_4H_{10} = 38/60/2$, flushed at 5 refills per day.[1] During an entire year of tests, starting from May 2002, the temperature ranged from 20 to 30 °C, the external relative humidity was between 20% and 50% and the pressure around 900 mbar. Due to the use of copper pipes in the gas system, about one half of the external humidity was measured in the gas entering the chambers. The long-term operation test has then been repeated, starting from August 2003, using the gas mixture $Ar/C_2H_2F_4/i\text{-}C_4H_{10} = 76/20/4$ with the addition of 0.7% SF_6. During the tests, the applied voltage was not kept constant in order to take into account the environment temperature and pressure variations [6].

3. Experimental results

In the following analysis, all the voltages, V_{app}, applied with absolute temperature T and pressure

[1] Actually our primary idea was to use the mixture 48/48/4, but that was not possible due to the limitation of the mass flow meters.

P, have been rescaled to $T_0 = 293\,\mathrm{K}$ and $P_0 = 900\,\mathrm{mbar}$, according to the relationship $V = V_{app} \times T/T_0 \times P_0/P$ [6]. Besides the correction of the applied voltage, operating currents and counting rates, at fixed rescaled voltage V, have a residual dependence on the absolute temperature [7], probably because of the change in the electrode resistivity.

In Fig. 1 the currents of RPC1, RPC2 and RPC3 are shown as a function of the time of operation. The chambers were flushed with a gas mixture $Ar/C_2H_2F_4/i\text{-}C_4H_{10} = 38/60/2$, at a rescaled voltage ranging from 8.4 kV to 8.8 kV. An increase of the current was observed for RPC1, starting from day 110, and for RPC2, starting from day 50. An attempt to invert the voltage polarity for one month (see RPC1 data from day 305 to day 330 in Fig. 1) did not succeed in reducing the operating current.

Such an increase of the current is due to the increased detector noise, as can be seen in Fig. 2,

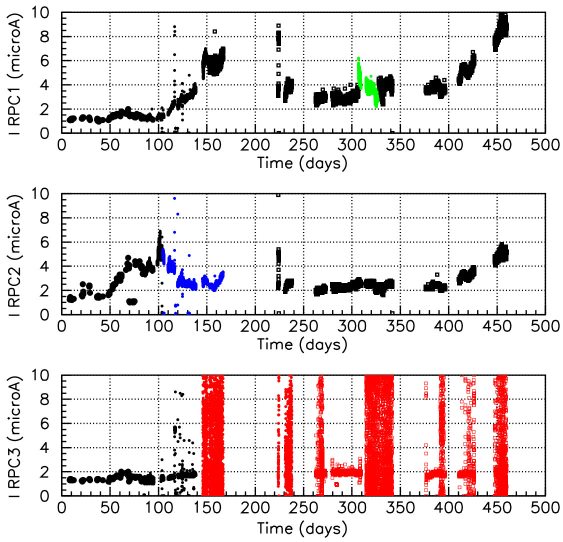

Fig. 1. Time evolution of the operating currents of RPC1, RPC2 and RPC3 with the gas mixture $Ar/C_2H_2F_4/i\text{-}C_4H_{10} = 38/60/2$. The current spikes of days 120 and 225 were due to gas system failures. The final increase after day 400 happened in summer 2003, when the temperature reached values around 30 °C. From day 305 to day 330 RPC1 was operated with the HV polarity inverted. From day 95 to day 170 RPC2 was flushed at 10 refills/day instead of 5. After day 150 RPC3 was operated in limited current, with about 200 V undervoltage, still in the efficiency plateau.

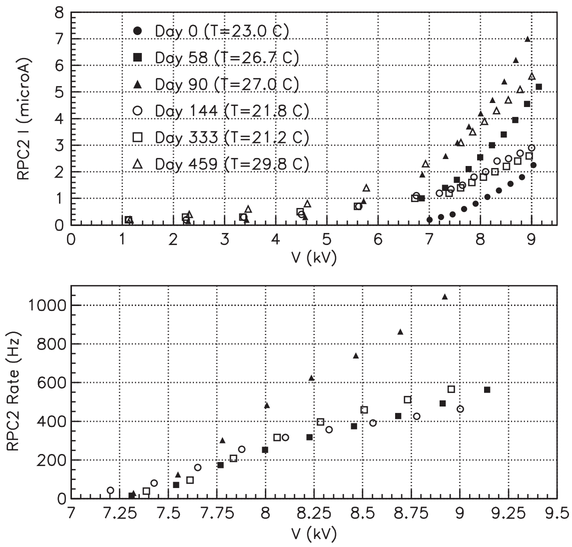

Fig. 2. Current (upper plot) and rate (lower plot) vs rescaled voltage characteristics measured in different operating days of RPC2. Day 0 = start of the test. Day 58 = beginning of current increase. Day 90 = further increase of the current, before the gas flow doubling. Day 144 = stop of the double gas flow treatment. Day 333 = 160 days of operation after the end of the treatment. Day 459 = end of the test.

which shows the current and the counting rate of RPC2 as a function of the rescaled voltage in different days of operation. A noise scan performed on RPC2 by discriminating at 40 mV the analogic signals of the readout strips has shown that the noise is localized in few strips, in the edge regions opposite to the grooves side.

The operating current increase has been cured on RPC2 by doubling the gas flow from 5 to 10 refills/day. After this treatment, the noise disappeared with an increase of the dark current at low operating voltage. The chamber behaviour remained stable even after having reestablished the normal gas flow (see Fig. 2).

The effectiveness of the treatment could be due to an increase of the electrode resistivity [8], therefore we have measured it by filling the detectors with pure Argon [9]. The average electrode resistivity measured after the double gas flow treatment at $T = 20\,°\mathrm{C}$ was $\rho(\mathrm{RPC2}) = 7.8 \times 10^{11}\,\Omega\,\mathrm{cm}$, while the ones measured for RPC1 and RPC3 were 8 and $4.9 \times 10^{11}\,\Omega\,\mathrm{cm}$, respectively. Unfortunately, a resistivity measurement at the beginning of the test is missing, but given the typical resistivity values spread at the production (between 5 and $10 \times 10^{11}\,\Omega\,\mathrm{cm}$), we can conclude that the resistivity of RPC2 electrodes has not changed dramatically.

The operating current of RPC3 was subject from time to time to high and fast oscillations due to external discharges in the HV circuit. The detector has been therefore operated in limited current, with 200 V undervoltage, without observing an increase of the noise.

The efficiency of the three RPCs considered has been monitored till day 333, with no efficiency loss. A final and detailed measurement of the efficiency and of the noise will be performed in the Quality Control Station, designed for testing the OPERA RPCs before their installation [10].

The three RPCs produced according to the present procedures, RPC4, RPC5 and RPC6, do not show an increase of the operating current after 360 days of operation. The efficiency and the counting rate of RPC4 have been monitored from time to time during the whole test, remaining stable. The currents of RPC5 and RPC6 have oscillations similar to those of RPC3, but lower. This fact can be explained with the presence of an insulating adhesive tape on the edge frame of the detectors. Moreover, in the RPCs to be installed in OPERA, the high-voltage solderings will be covered with hot melt, for a better insulation.

The long-term operation test is being repeated with a gas mixture $Ar/C_2H_2F_4/i\text{-}C_4H_{10} = 76/20/4$ with the addition of 0.7% SF_6 at a rescaled operating voltage of $6.6 \pm 0.1\,\mathrm{kV}$, about two kV below the one with the previous mixture. In the first 60 days of operation the currents of the six RPCs under test remained stable and lower with respect to the ternary mixture. Also the current oscillations of RPC3 decreased, because of the lower applied voltage.

4. Conclusions

In the long-term operation test of streamer operated RPCs, we have observed an increase of the operating current for the detectors produced according to old techniques. The interested chambers do not show an efficiency loss, and, moreover, the effect seems to be reversible by operating temporarily the RPCs at a high gas flow (10 refills/day). We also have observed voltage dependent external HV discharges causing fast and large oscillations of the current; detectors presenting this problem can be operated in limited current.

The present production procedures improve the RPCs performances, both in terms of operating current stability and of external discharges.

In order to avoid detector damages induced by HF production, we are investigating the possibility of reducing the tetrafluoroethane concentration with the addition of small quantities of SF_6. Such mixtures have a decreased quenching power, but also lower operating voltages and currents. On the basis of the first 60 days of long-term operation test with a SF_6-added gas mixture, the results look promising, with a lower operating current and also a decreased oscillation of the current induced by external discharges.

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